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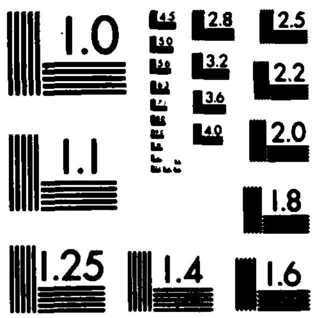

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by

Virgil Stanciu

EDITED TRANSLATION

FTD-ID(RS)T-1561-82 9 December 1982

MICROFICHE NR: FTD-82-C-001650

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English pages: 9

Source: Buletinul Institutului Politehnic "Gheorghe Gheorghiu-Dej" Bucuresti, Seria Mechanica, Vol. 43, Nr. 2, 1981, pp. 77-84

Country of origin: Romania
Translated by: LEO KANNER ASSOCIATES
F33657-81-D-0264
Requester: FTD/TQTA

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GENERALIZATION OF THE AIR-JET PROPULSION SYSTEMS, THE "N" FLOW TURBO-JET ENGINE

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The present paper has as task the establishment of new possibilities of investigating the performances of airspace propulsion systems, on the basis of the characteristics and performances of a generalized propulsion system — the „n" flow turbo-jet engine.

Out of the analysis of the performances of this engine, the known solutions are obtained by particularization: the turbo-jet engine, with simple flow (MTRSF), the turbo-jet engine with turbo-flow (MTRDF) and the turbo-propulsion engine (MTP). There are also emphasized, as an aplication, the advantages of the utilisation of turbo-jet engine with triple flow.

INTRODUCTION

The problem of improvement of the performances of air jet engines, imposed by the severe restrictions imposed on modern air transport (reduction of chemical and noise pollution, increase of the traction forces, reduction of the fuel consumption) was solved partly by introducing in 1958 a new type of engine, a turbojet engine with double flow.

From the functional point of view this engine represents the junction between the two existing propulsion systems, the turbopropeller engine and the turbo-jet engine.

The increase of the yield of the proportion plant, the propeller by the creation and introduction of a new flux of air which surrounds the primary flux makes it possible to improve considerably the noise and to increase the performances of the turbopropeller engine. We obtain thus a turbo-jet engine very similar to the MTRSF (turbo-jet engine with simple flow) although of higher characteristics.

It may be affirmed that the turbo-jet engine with double flow represents at the same time the extension of the turbo-jet engine with simple flow by emphasizing and accentuating the functional and geometrical characteristics of the primary networks of the axial compressor.

Starting from this observation we can imagine by generalization a propulsion system in which each diffuser network or a group of networks generate an air flux as shown in Figure 1.

Thus there is a possibility of building a turbo-jet engine with a larger number of flows (theoretically infinite) by which the performances are improved considerably providing unlimited possibilities of combining the parameters on which the letter depends.

This system is called turbo-jet engine with "n" flows.

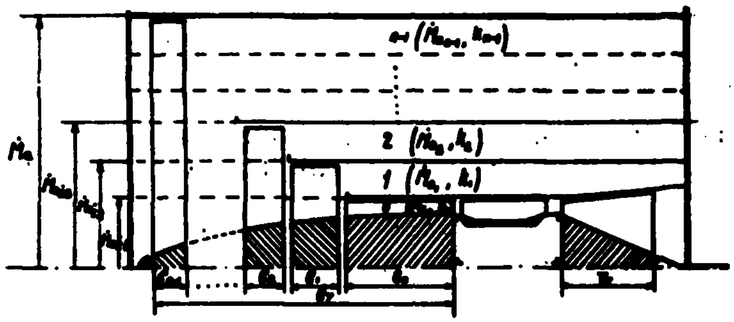

Figure 1: Basic scheme of the turbo-jet engine with "n" flows.

1. Main functional parameters of the engine are characterized either by the flow "i" or the entire engine.

a) Parameters of the air flow "i":

Ma_i, rate of flow of air circulating through the system "i";

l^*_{cil} mechanical work of compression accomplished by the compressor stage of the system "i";

l^*_{ci} mechanical work of compression of air given by the number of stages the compressor of the "i" system specifically $l^*_{ci} = p_i$ by l^*_{cil} in which p_i represents the number of stages of the "i" system.

l^*_{ciT} total mechanical work of compression of the air in the "i" system. This takes into account the contribution of other networks, specifically:

$$l^*_{ciT} = \sum_{j=i}^{n-1} l^*_{cj}, \qquad (2)$$

n being the number of flows.

p_{iT} represents the total number of stages of the axial compressor of the "i" system,

$$p_{iT} = \sum_{j=i}^{n-1} p_j \qquad (3)$$

K_i is the double flow factor of order i representing the ratio of the flow rate of air of the "i" system and the total flow rate of air of the corresponding internal system, M_{aIT}

$$K_i = \frac{\dot{M}_{ai}}{\dot{M}_{ali}} \qquad (4)$$

in which

$$\dot{M}_{ali} = \sum_{k=0}^{i-1} \dot{M}_{a_k}. \qquad (5)$$

- $K_i^{(i)}$ flow factor of order "i", specifically:

$$K_i^{(i)} = \frac{\dot{M}_{ali}}{\dot{M}_{a_0}} \qquad (6)$$

it is apparent that:

$$K_i^{(i)} = \prod_{p=1}^{i-1} (1 + K_p) \qquad (7)$$

b) Parameters of the engine:

-Ma, total rate of flow of air carried by the engine:

$$\dot{M}_a = \sum_{i=0}^{n-1} \dot{M}_{ai} \qquad (8)$$

or introducing Mai we obtain the relation

$$\dot{M}_a = \dot{M}_{a_0} \cdot \sum_{i=0}^{n-1} K_i \cdot K_i^{(i)} \qquad (9)$$

- K_e equivalent double flow factor defined as:

$$K_e = \sum_{i=0}^{n-1} K_i \cdot K_i^{(i)} - 1 \qquad (10)$$

In this situation the total rate of flow of air becomes:

$$\dot{M}_a = \dot{M}_{a_0}(K_e + 1) \qquad (11$$

A relation which allows the comparison with the known double flow turbo-jet engine.

2. Condition of Stable Operation of the Generalized Turbo-Jet Engine

Just as in the case of known systems, the condition of stable operation with the given speed of revolution of the turbo-compressor group is the equality of the power generated by the turbine P_T and the power consumed by the compressor P_c, providing we can disregard the power consumed by the engine units as well as the losses of energy by the bearings of the engine, specifically:

$$P_T \simeq P_c \qquad (12)$$

Keeping in mind the fact that the power consumed by the compressor is the sum of the powers consumed by the compressor stages of each system we have:

$$P_c = \sum_{i=0}^{n-1} P_{ci} \qquad (13)$$

but since:

$$P_{ci} = \dot{M}_{ai} \cdot l_{ci}^{*} \qquad (14)$$

the result is: $$P_c = \sum_{i=0}^{n-1} \dot{M}_{ai} \cdot l^*_{ci-1} \qquad (15)$$

in accordance to relation 9:

$$\dot{M}_{ai} = K_i \cdot K_i^{(i)} \cdot \dot{M}_{a_0}$$

and introducing:

$$P_c = \dot{M}_{a_0} \cdot \sum_{i=0}^{n-1} l^*_{ciT} \cdot K_i \cdot K_i^{(i)} \qquad (16)$$

with the condition:

$$K_0 = 0 \,;\; K_0^{(0)} = 1 \,;\; K_1^{(1)} = 1. \qquad (17)$$

On the other hand the power generated by the turbine may be expressed with the relation:

$$P_T = \dot{M}_{a_0} \cdot l^*_T \qquad (18)$$

in which l^*_T represents specific mechanical work produced by the turbine of the engine.

Assuming the relation 16 and 18 to be equal, the relation 19 is derived:

$$l^*_T \simeq \sum_{i=0}^{n-1} l^*_{ciT} \cdot K_i \cdot K_i^{(i)} \qquad (19)$$

which represents the condition of stable operation of the turbo-jet engine with "n" air flows. Since the emphasis is taken that the mechanical work accomplished by the compressor stage is constant, specifically $l^*_{cil} = l^*_1$ constant, we obtain:

$$l^*_T = l^*_1 \cdot \sum_{i=0}^{n-1} p_{iT} \cdot K_i \cdot K_i^{(i)} \qquad (20)$$

With regard to the mechanical work obtained in the combined system of the turbine it may be affirmed that the latter is limited on one hand by the maximum temperature T^*_3 and on the other hand by the possibility of building complete expansion, $P_4 = P_H$.

It may therefore be estimated that the ratio l^*_T / l^*_1 is limited in the present stage of the aerojet engines. Therefore the conclusion may be drawn that:

$$\sum_{i=0}^{n-1} p_{iT} \cdot K_i \cdot K_i^{(i)} = C \qquad (21)$$

Analyzing the statistics of some of the existing solutions of turbo-jet engines with single and double flow we arrive at the conclusion that C = 13-19, that is any combination of the parameters of the flow requires the progress within these constant limits.

3. Specific Performances of the Generalized Turbo-Jet Engines

From the definition of the traction forces for an air jet propulsion system we obtain:

$$F = \sum_{i=0}^{n-1} F_i \qquad (22)$$

in which $F_i = M_{ai} \cdot F_{spi}$ represents the traction force of the "i" system. On the other hand:

$$F = \dot{M}_{a0} \cdot F_{sp}$$

that is the specific force of the engine becomes:

$$F_{sp} = \sum_{i=0}^{n-1} K_i \cdot K_i^{(i)} \cdot F_{spi} \qquad (23)$$

The specific force of the "i" system, F_{spi} may be explicit:

$$F_{spi} \simeq C_{5i} - V \qquad (24)$$

in which V is the speed of operation and C_{5i} the speed of evacuation of gases. It should be kept in mind that the gas expansion in any system is complete.

Consequently:

$$F_{sp} = \sum_{i=0}^{n-1} K_i \cdot K_i^{(i)} \cdot C_{5i} - V \sum_{i=0}^{n-1} K_i \cdot K_i^{(i)} \qquad (25)$$

In the case of operation of engine with fixed point V = 0, the specific force has the form:

$$F_{sp_0} = \sum_{i=0}^{n-1} K_i \cdot K_i^{(i)} \cdot C_{5i_0} \qquad (26)$$

For calculating the speed of evacuation of the fluid from the "i" system, C5i the ollowing relation is applied:

$$C_{5i} = \sqrt{2 \cdot \frac{X_i}{K_i \cdot K_i^{(i)}} \cdot E \cdot \eta_i \cdot \eta^*_{Ti} + V^2} \qquad (27)$$

in which we have the following rotations:

-X_i by E the component of the available energy E of the engine which relates exclusively to the "i" system;

-η^*Ti yield of the turbine which drives the compressor of the "i" system;

-ηi, effective yield of the "i" system;

It is apparent that the available energy E may be expressed with the formula:

$$E = l^*_T - l^*_{coT} \qquad (28)$$

or:

$$E = \sum_{i=0}^{n-1} l^*_{ciT} \cdot K_i \cdot K_i^{(i)} \qquad (29)$$

since the expansion in the turbine is complete.

The speed of evacuation of the gases of the primary "o" system is:

$$C_{5_0} = \varphi_{ar} \cdot \sqrt{2\left(1 - \sum_{i=1}^{n-1} X_i\right) \cdot E} \qquad (30)$$

in which φar is the coefficient of the loss of speed in the adjustment of the engine.

As regards the specific consumptions of fuel of this engine, it may be calculated from:

$$C_{sp} = \frac{3600}{P_{ci} \cdot \zeta_{ca}} \cdot \frac{i_3^* - i_2^*}{F_{sp}} \qquad (31)$$

in which P_{ci} is the minimum calorific power of the fuel ξ_{ca} the coefficient of improvement of combustion, i_3^* the maximum enthalpy of the combustion gases and i_2^* the enthalpy of air at the end of compression.

4. Special Case of the Generalized Turbo-Jet Engine

The relations established up to now may be specified as follows:

a) n = 1 turbo-jet engine with simple flow:

$$K_0 = 1, \; K_0^{(0)} = 1$$
$$l_T^* = l_{C0T}^*$$

b) n = 2 turbo-jet engine with double flow;

$$K_1 = K, \; K_1^{(1)} = 1$$
$$l_T^* = l_{C0T}^* + K \cdot l_{C1T}^*$$

c) n = 3 turbo-jet engine with triple flow;

$$K_1 = K_1, \; K_1^{(1)} = 1, \; K_2 = K_2, \; K_2^{(2)} = 1 + K_1$$

therefore:

$$l_T^* = l_{C0T}^* + K_1 \cdot l_{C1T}^* + K_2(1 + K_1) l_{C2T}^*$$

d) if we assume $K \to \infty$ we find the turbopropeller engine.

$$l_T^* = l_{C0T}^* + \frac{Pef_{sp}}{\eta_r},$$

in which Pef_{sp} is the specific effective power of the engine while η_r represents the yield of the reduction gear of the engine.

5. Studies of the Turbo-Jet Engine with Triple Flow

In cases when the engine has three air flows, the specific force at the fixed point is:

$$F_{sp_0} = C_{S0_0} + K_1 \cdot C_{S1_0} + K_2(1 + K_1) C_{S2_0}$$

in which:

$$C_{S0_0} \simeq \sqrt{2(1 - X_1 - X_2)E}$$
$$C_{S1_0} \simeq \sqrt{2\frac{X_1}{K_1} \cdot E \cdot \eta_T^* \cdot \eta_1}$$
$$C_{S2_0} \simeq \sqrt{2\frac{X_2}{K_2(1+K_1)} \cdot E \cdot \eta_T^* \cdot \eta_2}$$

Assuming that $\eta_1 = \eta_2 = \eta$ the specific force becomes:

$$F_{sp_0} = \sqrt{2E}\,\{\sqrt{1 - X_1 - X_2} + \sqrt{\eta_T^* \cdot \eta}\,[\sqrt{K_1 \cdot X_1} + \sqrt{X_2 K_2(1+K_1)}\,]\}$$

In this form it is possible to optimize the specific forces as a function of X_1 and X_2. Since $F_{sp_3} = f(X_1, X_2)$ is a function with two variables, then applying the criteria of optimization of these functions we find:

$$X_{1opt} = \frac{1}{1 + \frac{K_2(1+K_1)}{K_1} + \frac{1}{K_1 \cdot \eta_T^* \cdot \eta}}$$

and

$$X_{2opt} = \frac{1}{1 + \frac{K_1}{K_2(1+K_1)} + \frac{1}{K_2(1+K_1) \cdot \eta_T^* \cdot \eta}}$$

It makes it possible to show mathematically that all the conditions are satisfied for X_{1opt} and X_{2opt} assuming the maximum of the specific forces.

As application of what was established in this paragraph we may carry out a small comparison of the performances of the two turbo-jet engines, one with double flow the other with triple flow through which the same flow of air passes Ma = 150 Kg/s.

Thus in the case of MTRTF·(turbo-jet engine with triple flow):

$$k_1 = 1,\ k_2 = 1.\ \eta_T^* = 0.85,\ \eta = 0.8$$

$$M_{a_0} = 50\ \text{Kg/s},\ M_{a_1} = 50\ \text{Kg/s}.\ M_{a_2} = 50\ \text{Kg/s}$$

Under these conditions:

$$X_{1opt} = 0{,}22;\ X_{2opt} = 0{,}44,$$

$$F_{sp_3} = 1{,}7374 \cdot \sqrt{2E}.$$

In the situation of the MTRDF (turbo-jet engine with turbo flow):

$$K_r = 2,\ X_{opt} = 0{,}576$$

while:

$$F_{sp_2} = 1{,}53 \cdot \sqrt{2E}.$$

The result is that in the same frontal section,

$$F_{sp_3} > F_{sp_2}$$

the increase being about 15 percent. This increase of the forces corresponds to the considerable decrease in the specific consumption of fuel.

CONCLUSIONS

From the study described the following essential conclusions may be drawn:

-the generalized turbo-jet engine has the advantage of a specific performance superior to that of existing engines (higher specific force and lower specific fuel consumption) in thesame frontal section, that is the same reaction in front;

-the generalized turbo-jet engine may assure the same performances as that of a classic engine but using a smaller rate of flow of air;

-the possibility of optimization of the generalized turbo-jet engine is of a very practical nature and does not assume a large volume of calculation.

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